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THE GALE OF JULY 29, 1956

By D. M. HOUGHTON, M.Sc.

Storm force winds and heavy rainfall accompanied a depression of exceptional intensity for July as it crossed England from the Scillies to the Wash on Sunday, July 29, 1956. In the English Channel the ketch *Moyana* on her victorious return from Lisbon after sailing in the Torbay to Lisbon race, was among the yachts which foundered. Many others, in harbours, came to grief as they were torn from their moorings. On land six people were killed by falling trees and many had to be evacuated from camping sites which were flattened by the gale; even caravans were overturned. Severe flooding occurred in north Wales and landslides blocked the London–Holyhead road. Farmers and fruit growers suffered heavily as corn was flattened and fruit trees were stripped.

On Wednesday, July 25 a small frontal wave broke away from a weak parent depression over eastern America and progressed across the Atlantic on the south side of a belt of westerly thermal winds. For three days it travelled almost due east along latitude 47°N. at a speed of about 30 kt. with central pressure between 1000 mb. and 1004 mb.

The 500-mb. charts show a large-scale trough intensifying to the west of the British Isles and by 0300 G.M.T. on Saturday, July 28 it had a well defined axis from Iceland to the Azores. As it developed further the axis swung eastwards, pivoting on Iceland, and at 0300 G.M.T. on the 29th it lay from Iceland to Cape Finisterre. Though the flow around the trough was fairly strong for a summer situation it was in no way unusual and cannot have been solely responsible for the extraordinary features of the subsequent surface developments.

While the wave was crossing the Atlantic much of the British Isles was under the influence of a declining anticyclone whose centre was moving eastwards across northern France. By Friday morning the pressure was almost uniform over the whole country and a quasi-stationary front was giving rain over southern Scotland. Pressure continued to fall steadily over the whole country and by early on Saturday a small depression had formed over northern England with widespread and severe thunderstorms. Pressure remained relatively high to the south of Greenland and as the pressure fell over the British Isles increasing northerly winds brought cold air southwards over the eastern Atlantic. Late on Friday the 27th the wave passed the axis of the thermal trough associated

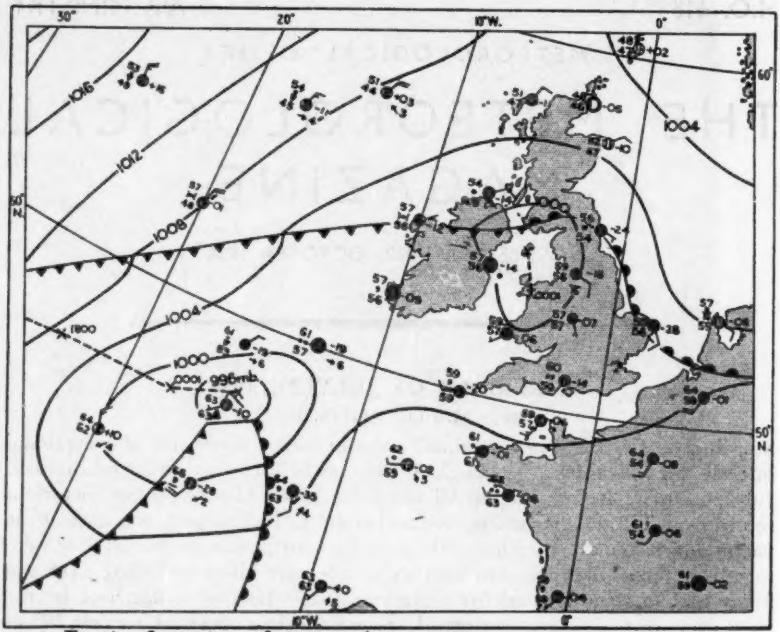


FIG. 1—SYNOPTIC CHART, 0600 G.M.T., JULY 28, 1956

with the large-scale upper trough in the east Atlantic and began to turn east-north-east deepening slowly in the weakly cyclogenetic area on the forward side of the trough. Figs. 1 and 2 show the 0600 G.M.T. surface chart and the 1000–500-mb. thickness chart for 0300 G.M.T. on Saturday.

The character of the air in the lowest few thousand feet which was over the British Isles as the depression approached south-west England may have been important. Prolonged thundery rain and thunderstorms over Scotland, northern England and Northern Ireland resulted in almost saturated air in the lower troposphere with a wet-bulb potential temperature of about 14·5°C. This was almost stagnant. Somewhat similar air over central and southern England drifted away into the North Sea and was replaced by drier and more stable air ahead of the warm front. The relevant ascents show that the fronts associated with the depression were little more than discontinuities in surface dew point. The Camborne 1400 G.M.T. ascent on 28th shows no warm frontal stability aloft. This is borne out by the absence of any well defined belt or area of rain to the south of the depression centre. Also the low remained on the warm side of the belt of strong 1000–500-mb. thickness gradient and created little distortion in it.

Some of the colder air to the west of Ireland was drawn into the circulation late on Saturday and by midnight the low had deepened to about 980 mb. By this time the gradient wind had increased to about 50 kt. over a radius of about 200 miles around the centre. Between 1800 G.M.T. on 28th and 0600

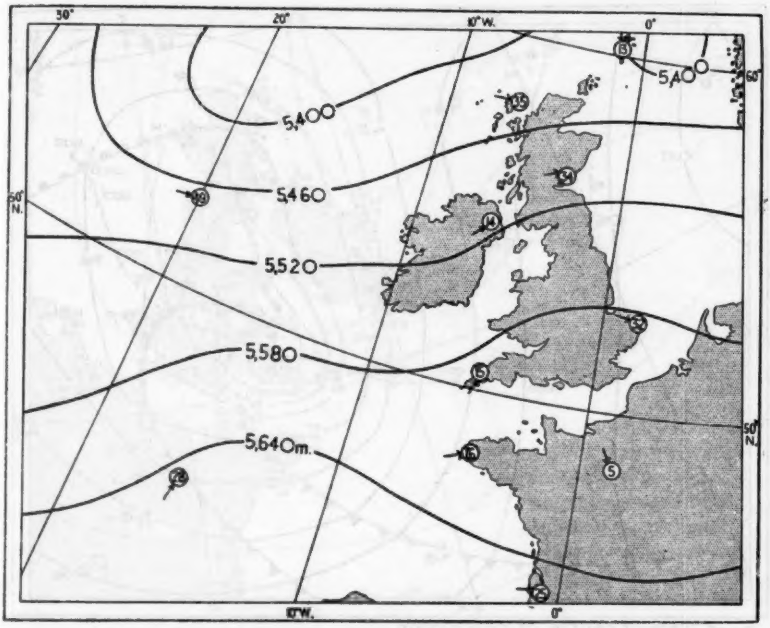


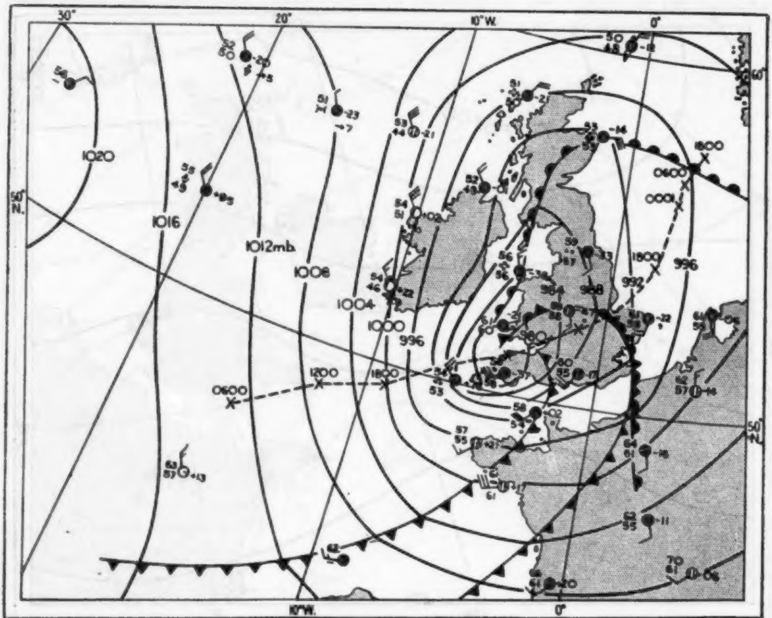
FIG. 2—1000–500-MB. THICKNESS CHART, 0300 G.M.T., JULY 28, 1956

The directions and magnitudes (in kt.) of thermal winds are indicated by arrows and encircled numbers.

G.M.T. on the 29th when most of the deepening occurred the speed of the depression decreased to about 17 kt. As it entered the Bristol Channel an area of heavy rain developed over west Wales as the warm moist surface air was drawn southwards. This air was warm with respect to the air at higher levels and it may have been partly responsible for the rapid developments during Sunday morning. The very heavy rain in the rear of the depression and exceptionally severe gales on its western and southern flanks are suggestive of unusual convergence of air in the lower layers just west or south-west of the centre.

Just before the depression reached its maximum depth (about 974 mb.) at about 0800 G.M.T. on 29th a very rapid rise of pressure set in over a confined area in its wake. The first sign of such a rise was at Scilly at 0600 G.M.T. when an hourly figure of 2·8 mb. was reached. During the next few hours tendencies of over 10 mb. in three hours were reported at almost all stations in south-west England. At Exeter three-hourly tendencies reached 13·1 mb. and in one hour (0800 to 0900 G.M.T.) the pressure rose by 5·3 mb. The severe gales which accompanied these developments reached 58 kt. at 0600 G.M.T. at the Lizard with a gust to 87 kt. At St. Mawgan a gust of 76 kt. was reached at 0600 G.M.T. and at Culdrose a mean hourly wind of 46 kt. with a gust of 74 kt. occurred at the same time.

The depression continued in its east-north-easterly track across England and by 1400 G.M.T. was over the Wash and had filled to 980 mb. The winds were



x---x Track of centre of depression

FIG. 3—SYNOPTIC CHART, 0600 G.M.T., JULY 29, 1956

still blowing at above gale force to the south and south-west of the centre, and over south-east England gusts exceeded 60 kt. in several places. The maximum recorded at Shoeburyness was 52 kt. at 1200 G.M.T. with a gust to 66 kt. The rain in the rear of the depression eased during the forenoon and by 1400 G.M.T. only sporadic outbreaks of moderate rain were being reported. The remainder of the depression track into the North Sea is shown in Fig. 3.

The lowest pressure reported was at Yeovilton at 0800 G.M.T. when the barometer (reduced to M.S.L.) read 976·6 mb. Since the depression was some 30 miles to the north at the time the central pressure probably fell to about 974 mb. The only July depression of comparable depth this century crossed central and northern districts of England on July 6, 1922 and the record minimum of 976·0 mb. was recorded at Tynemouth. Owing to the more southerly track of the later depression the pressure at Kew reached a new low record for July. A mean-sea-level pressure of 981·7 mb. was recorded at 1050 G.M.T. on the 29th. The previous lowest in records dating back to 1869 was 983·5 mb. in July 1922.

Winds on July 29, 1956 were far in excess of any previously recorded in the British Isles in the month of July. The highest gusts recorded on July 6, 1922 were 68 kt. at Scilly and 66 kt. at Calshot.

Rainfall between 2100 G.M.T. on 28th and 0900 G.M.T. on the 29th was 41 mm. at Valley, 32 mm. at Pembroke Dock and 24 mm. at St. Mawgan.

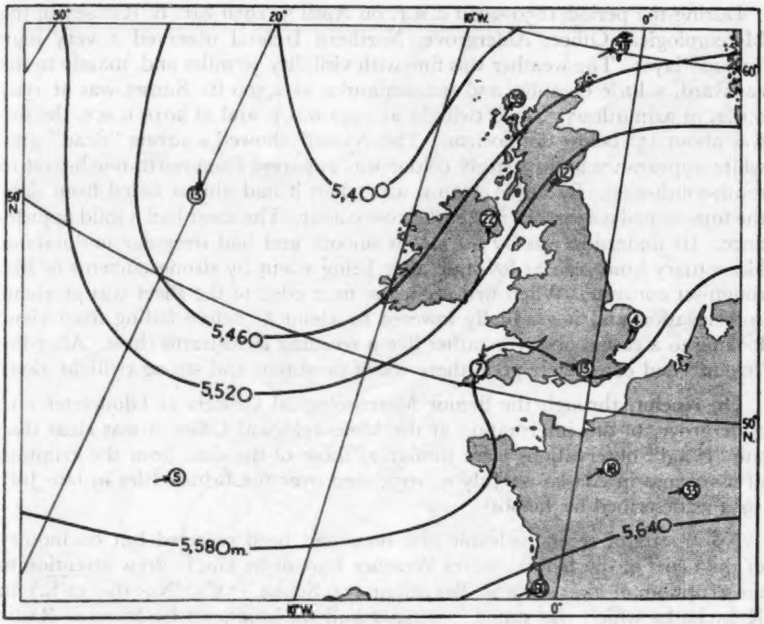


FIG. 4—1000–500-MB. THICKNESS CHART, 0300 G.M.T., JULY 29, 1956

The directions and magnitudes (in kt.) of thermal winds are indicated by arrows and encircled numbers.

The picture would not be complete without mention of the floods in north and east Scotland on the following day. During the 24 hr. from 2100 G.M.T. on Sunday a rainfall of 65 mm. was measured at Kinloss, 57 mm. at Cape Wrath and 42 mm. at Aberdeen. Bridges were washed away, homes flooded and road and rail services dislocated.

DUST IN THE STRATOSPHERE OVER WESTERN BRITAIN ON APRIL 3 AND 4, 1956

By G. A. BULL, B.Sc., and D. G. JAMES, Ph.D.

Between 1000 and 1045 G.M.T. on April 3, 1956, Wing Cmdr Martin, Chief Test Pilot of the Gloucester Aircraft Company and his navigator Mr. Varley observed from 50,000 ft. a layer of "cloud" estimated to be at 55,000 ft. The cloud was observed to cover the whole of the south-west part of England and to be in bands or streaks running north to south with minor ripples on the underside running north-east to south-west. The colour of the "cloud" was off-white; viewed from directly below it was transparent and the disc of sky above seemed a vivid blue. The underside of the cloud closely resembled an oily sea. On a flight on April 4 the same pilot passed through a layer of cloud 50 ft. thick at 40,000 ft. which was considered to be rather more lumpy in appearance than on the previous day. The tropopause was at a height of 11 Km. (36,000 ft.) so this "cloud" was well in the stratosphere.

During the period 1850–2010 G.M.T. on April 3, 1956 Mr. B. Ramsey of the Meteorological Office, Aldergrove, Northern Ireland observed a very high "cloud" layer . The weather was fine with visibility 30 miles and, mainly to the eastward, a little cumulus and stratocumulus at 2,500 ft. Sunset was at 1904 G.M.T. at azimuth 275°, civil twilight at 1942 G.M.T. and at 2010 G.M.T. the sun was about 15° below the horizon. The "cloud" showed a strong "dead" grey white appearance and its steely colour was apparent from north-north-west to south-south-west. By about 2000 G.M.T. when it had almost faded from sight the tops turned a deep but rather flat rose colour. The sheet had a solid appearance. Its underside was by no means smooth and had irregular undulations like estuary sand seen at low tide after being swept by strong currents or like rough-set concrete. When first seen, the near edge of the sheet was at about 40° elevation and it gradually lowered to about 5° before fading from view, looking to a casual observer rather like a receding cirrostratus sheet. After the "cloud" had completely gone there was a persistent and strong twilight glow.

On receipt, through the Senior Meteorological Officers at Gloucester and Aldergrove, of this information at the Meteorological Office it was clear that the "cloud" observations were similar to those of the dust from the eruption of a volcano in Alaska on July 9, 1953 seen over the British Isles in late July 1953 as described by Jacobs[1].

No reports of recent volcanic eruptions had been received but on inquiry of the Chief of the United States Weather Bureau he kindly drew attention to an eruption of the volcano Bezymannaya Sopka (55°57′N., 160°32′E.) in Kamchatka which was stated in a news bulletin broadcast by Moscow Radio as having occurred at 1711 L.S.T. (0611 G.M.T.) on March 30, 1956. The Moscow report, some further details of which were obtained from the British Broadcasting Corporation, stated that the volcano in question erupted suddenly at the time given and that a cloud of ashes rose to a height of 20 Km. (67,000 ft.), accompanied by thunder and lightning lasting for 4 hr., and that an appreciable fall-out of volcanic ash had been registered at a distance of nearly 80 Km. from the volcano. After the end of the fall-out the air remained filled with volcanic dust. On the morning of March 31 the fall-out had been nearly 30 Kg. of volcanic ash per square metre near a vulcanological station some 40 Km. from the volcano. A second explosion occurred on April 1 with gases and ashes shooting up to 10 Km. A 1500-micron displacement of the earth's crust was recorded.

The Chief of the United States Weather Bureau stated in his letter that the dust was not seen over the United States but that a report of a heavy haze layer on April 3 at 10,000 ft. over Anchorage, Alaska had been received. By and large, however, Alaska was cloud covered.

The problem of determining from information on upper winds, the possibility of the "cloud" over the British Isles having been dust from the Kamchatka eruption was then studied in the Forecast Research Division.

It was reasonable to suppose that the "cloud" observed from Aldergrove was the same as that over Gloucester and its height was assumed to be near that of the 100-mb. level.

100-mb. charts were accordingly drawn for 0300 and 1500 G.M.T. for each of the days March 30 to April 3 inclusive. Unfortunately no data at 100 mb.

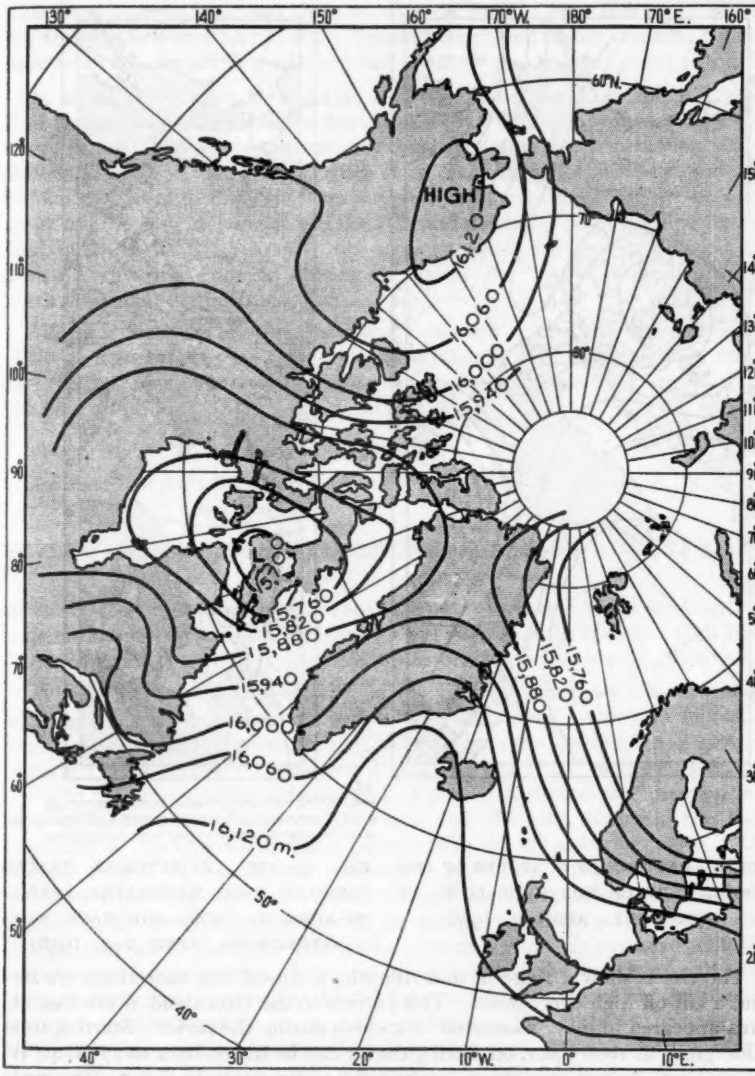


FIG. 1—PATTERN OF CONTOURS OF THE 100-MB. SURFACE NORTH OF 50°N. AT 1500 G.M.T., MARCH 31, 1956

were available from the Kamchatka–North Pole–Greenland area for the construction of the charts. Figs. 1 and 2 show the main features of the pattern of contours of the 100-mb. surface north of 50°N. at 1500 G.M.T. on March 31 and April 2 respectively.

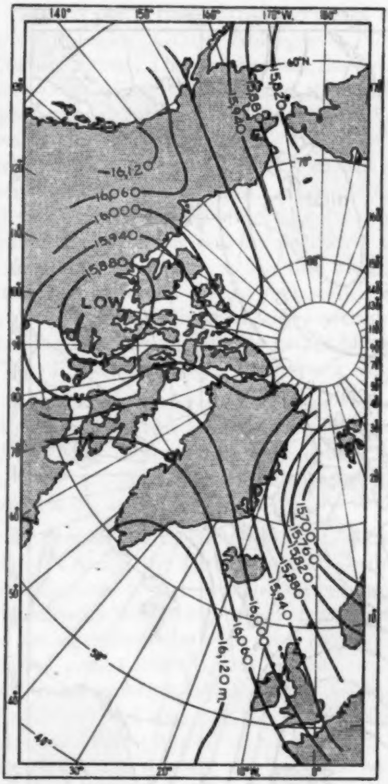


FIG. 2—PATTERN OF CONTOURS OF THE 100-MB SURFACE NORTH OF 50°N. AT 1500 G.M.T., APRIL 2, 1956

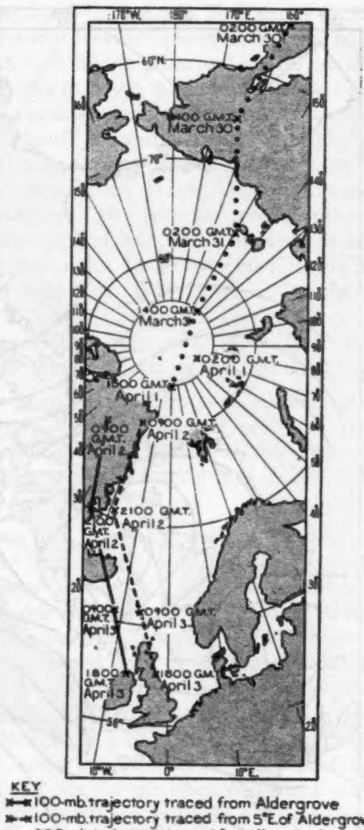


FIG. 3—AIR TRAJECTORIES TRACED FORWARD FROM KAMCHATKA (MARCH 30–APRIL 1, 1956) AND BACK FROM ALDERGROVE (APRIL 2–3, 1956)

The charts show a ridge in mid-Atlantic, a cut-off low near Hudson's Bay and a cut-off high over Alaska. This pattern in the Greenland–north Canada area appeared to move somewhat westwards during the period. Starting from Aldergrove at 1800 G.M.T. on April 3 the air can be traced back to 77°N, 40°W. by 0900 on the 2nd as is shown in the full-line trajectory in Fig. 3. The exact position of the last point is subject to more than normal error because of confluence in the flow pattern over Greenland. A trajectory starting from 5° east of Aldergrove would not be subject to the same doubt and gives a position at about 80°N. 20°W. at 0900 on April 2, as shown in the trajectory (pecked) in Fig. 3.

The great-circle distance from the volcano in Kamchatka to 80°N. 40°W. is rather more than 3,000 miles and the time interval available is about 75 hr.

This time interval is far too short to allow of travel round the upper low in the Hudson Bay area and so if the "cloud" originated in the eruption it must have come directly across the Polar basin at an average speed of about 40 m.p.h.

As noted already no information is available on winds at 100 mb. over Kamchatka but at 200 mb. over that area on March 30 the wind was southerly, 60–70 m.p.h. A trajectory at 200 mb. computed from this information is also shown (dotted) on Fig. 3 from which it is clear that if the winds at 100 mb. from Kamchatka to the Pole were not very different from those at 200 mb., air at 100 mb. would have crossed the Pole and reached a point north of Greenland by 1500 G.M.T. on April 1. As already stated a trajectory drawn back from Aldergrove at 100 mb. starting at 1800 on April 3 does reach a point in north Greenland by 0900 on April 2.

Allowing for errors of observation and analysis it it clear that the end points of the two trajectories are near enough together to give the fairly sure result that the dust seen over western Britain on April 3 could have originated in the volcanic eruption in Kamchatka on March 30.

REFERENCE

1. JACOBS, L.; Dust cloud in the stratosphere. *Met. Mag., London*, 83, 1954, p. 115.

SEVERE HAILSTORM AT TUNBRIDGE WELLS ON AUGUST 6, 1956

By R. E. BOOTH

After its worst hailstorm for more than 30 yr., Tunbridge Wells on August 6, presented a scene more like midwinter than August Bank Holiday, with hailstones in parts of the town shovelled up to 6 ft. high looking like snowdrifts.

A polar depression near Iceland on the 3rd was brought southward in an arctic air stream and became situated off the Hebrides by midday the following day. About that time tornado-like "funnels", always an indication of very disturbed conditions, were observed at Earls Colne near Colchester reaching down to the ground from a dense bank of cloud. A similar phenomenon was seen at Ramsgate at about noon the next day, the 5th; the cloud was then described as "looking rather like a parsnip with the tail swinging about". On Sunday, August 5 the polar low deepened considerably as it moved south from Northern Ireland to become centred over the Lizard at noon and over northern France 24 hr. later. Associated with the surface low there was a cold vortex in the upper air at 500 mb. This cold vortex moved slowly eastward with the surface low; 1000–500-mb. thickness values reached the minimum recorded for the month since 1949 while the thickness at Brest at 0300 G.M.T. on the 6th was an August extreme minimum. The tephigram (Fig. 1) shows the 0200 and 1400 G.M.T. ascents for Crawley. It will be seen that, during the early hours, the environment below 700 mb. was extremely unstable and very dry; and remained so, although to a somewhat reduced extent, during the afternoon. From the 3rd to the 5th there were showers and scattered thunderstorms over most of the British Isles, and early on Bank Holiday Monday thunderstorms broke out along the south coast from Kent to Devon and spread northward during the morning.

The storm which struck Tunbridge Wells was one of these and began about mid-morning with heavy rain and thunder. The hail started a little before noon

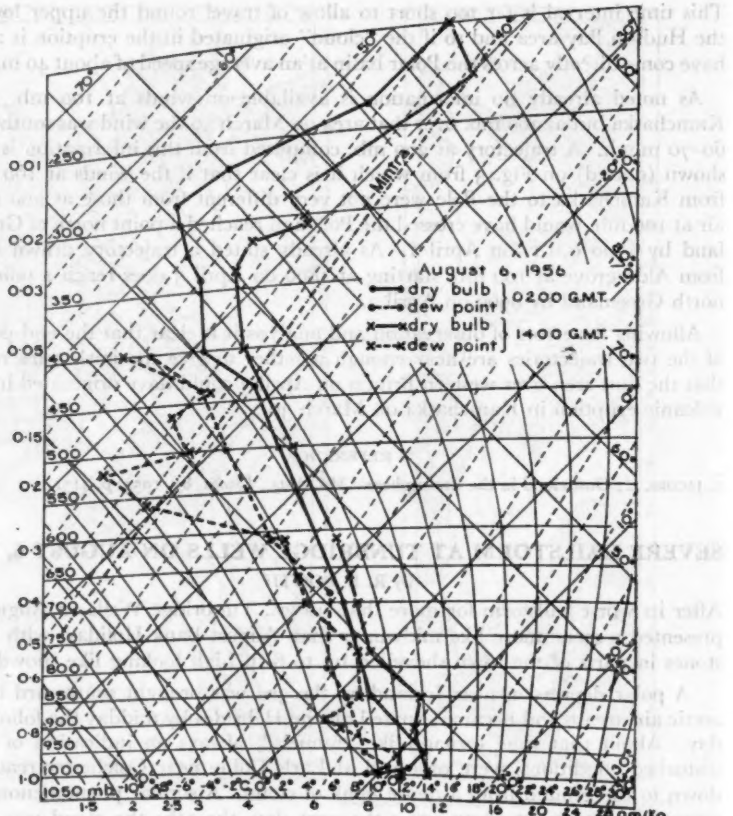


FIG. 1—TEPHIGRAM OF CRAWLEY ON AUGUST 6, 1956

and poured down with an unremitting and sustained intensity which was quite remarkable. Roads were soon blocked by hailstones; hailstones carried by rain-water quickly choked the drains and flood water rose rapidly (see photograph facing p. 304). The effects of the storm appeared to be greatest in the lower or "Pantiles" quarter of the town which resembles a basin and into which four wide main roads converge. Here hailstones and flood water were at times 3 ft. deep and there were hailstones in drifts of up to 4 ft. Bulldozers and mechanical shovels worked for 4 hr. to clear a passage for the traffic and when a way was cleared, cars had to pass between piles of frozen hailstones up to 6 ft. high. Undrifted hailstones covered most of the ground in the neighbourhood to a depth of 2 in.; they varied from ¼ in. to ¾ in. in diameter.

In spite of the intensity of the storm, structural damage appeared to be comparatively slight although St. James' Church was struck by lightning and hailstones broke through the roof of the Nevill Arms Hotel and went right through the ceiling into the bar. There was extensive flooding; a cinema

which was flooded was unable to open on time, and at the Castle Hotel hail was piled 6 ft. in the cellars and the draught beer is said to have been frozen solid.

The damage to growing crops was disastrous. Lettuce leaves were slashed and reduced to a quarter of their normal size and cabbages were cut to ribbons. Peas, beans and tomatoes were stripped of their leaves and pea pods were severely bruised and cut about. Hops over the whole storm area were hanging on the strings by bare stalks. Oats were literally threshed by the hail so that only the bare stalks remained and grain lay in piles on the ground. Fruit on trees hung bruised and cut, surrounded by torn and broken leaves (see photograph facing p. 305).

FREQUENCIES AND CORRELATION IN UPPER AIR DATA

By N. GOLDIE, B.Sc.

Introduction.—The subject of this article is a combination of upper air climatology and statistics. First, fundamental concepts in each of these are outlined briefly; then discussion proceeds to correlations in upper air data and frequency distributions of temperature, wherein probability paper is described, and thence to normal correlation surfaces and frequency distributions of wind vectors.

Troposphere and stratosphere.—The two lowest layers of the earth's atmosphere are known as the troposphere and stratosphere. The troposphere, in which, above the first 300 ft., temperature generally decreases with height, extends from the earth's surface to the tropopause, the latter being the boundary between troposphere and stratosphere. On the temperature record obtained from a single ascent of a sounding balloon, the tropopause usually shows up as a well marked discontinuity at which the fall of temperature with height either becomes suddenly much smaller, ceases or becomes negative. In fact it is very common to find in the lower stratosphere a complete reversal of the lapse rate characteristic of the troposphere. Average values of atmospheric pressure at the tropopause over a few stations in different latitudes are shown in Table I, with equivalent heights in feet and in kilometres.

TABLE I—AVERAGE LEVEL OF THE TROPOPAUSE

			Average tropopause level	Approximate equivalent height	
			mb.	ft.	Km.
Arctic Bay, Canada	73°N.	84°W.	302	29,000	9
Lerwick, Shetland	60°N.	1°W.	254	33,000	10
Larkhill, Wiltshire	51°N.	2°W.	233	36,000	11
Habbaniya, Iraq	33°N.	44°E.	Lower 220—180	40,000	12
			Upper 100— 85	55,000–60,000	17–18
Nairobi, Kenya	1°S.	37°E.	93	57,000	17

Poleward of latitude 45°, a single tropopause is generally evident which shows, on average, a gradual slope upwards from arctic through temperate latitudes. Within 25° or so of the equator, the tropopause is very much higher; and, between 25° and 45° of latitude, two tropopauses are apparent, presumably due to the overlapping of the polar and tropical tropopauses.

Discussion here is limited to the portions of the atmosphere in which observations of temperature and wind are made daily in many parts of the world, i.e. to the troposphere and lower stratosphere. Rough averages of the heights of selected pressure levels in these layers are shown in Table II.

TABLE II—AVERAGE HEIGHTS OF PRESSURE LEVELS IN LATITUDES 33°N.–60°N.

		Pressure (mb.)				
	1000	500	300	200	150	100
Rough average height ft.	300	18,000	30,000	39,000	45,000	53,000
Km.	...	5½	9	12	13½	16

Frequency diagrams.—The basic concepts considered in statistics are the frequency diagram and the correlation coefficient.

Suppose we have a set of upper air temperature observations ranging from, say, −75°F. to −25°F. We can group them into classes according to each 2°F. say of the range, and draw for each class a column to represent the number of occurrences. The result might be something like that shown at the bottom of Fig. 1. This type of frequency diagram is known as a histogram. If it is symmetrical and bell-shaped, one is tempted to fit to it a "normal" frequency curve. This has been done in Fig. 1. The superimposed curve represents the "normal" frequency distribution which has the same mean or average value as the observations and the same standard deviation.

The "normal" distribution, based on the theory of errors and known sometimes as the Gaussian distribution and sometimes as the Maxwellian, is used as a standard by which we may judge any linear distributions of frequencies. These may be either skew, humped or flat-topped (see Fig. 2). Where a set of observations conforms very closely to the normal distribution, it is as if there were a certain characteristic value approximated by the average, individual observations being random shots at this characteristic or "true" mean value.

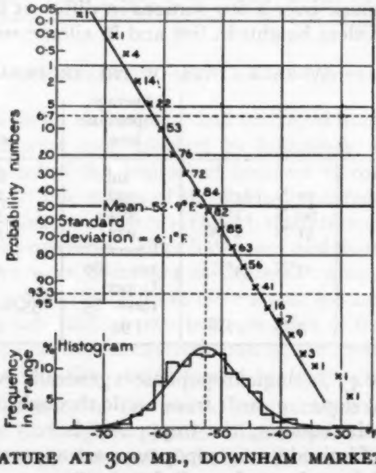


FIG. 1—TEMPERATURE AT 300 MB., DOWNHAM MARKET, APRIL 1946–51
Number of observations = 692

The standard deviation is a measure of the scatter of the observations about the mean value. If, for any observation X, we write $X = \overline{X} + x$, where $\overline{X}$ is the mean or average, then the root-mean-square of x is known as the standard deviation; that is

$$\text{standard deviation of } X = \sqrt{\left(\frac{1}{N}\sum x^2\right)},$$

where N is the number of observations.

Correlation.—If we have a related series of observations, Y, we may similarly write $Y = \overline{Y} + y$

and $$\text{standard deviation of } Y = \sqrt{\left(\frac{1}{N}\sum y^2\right)}.$$

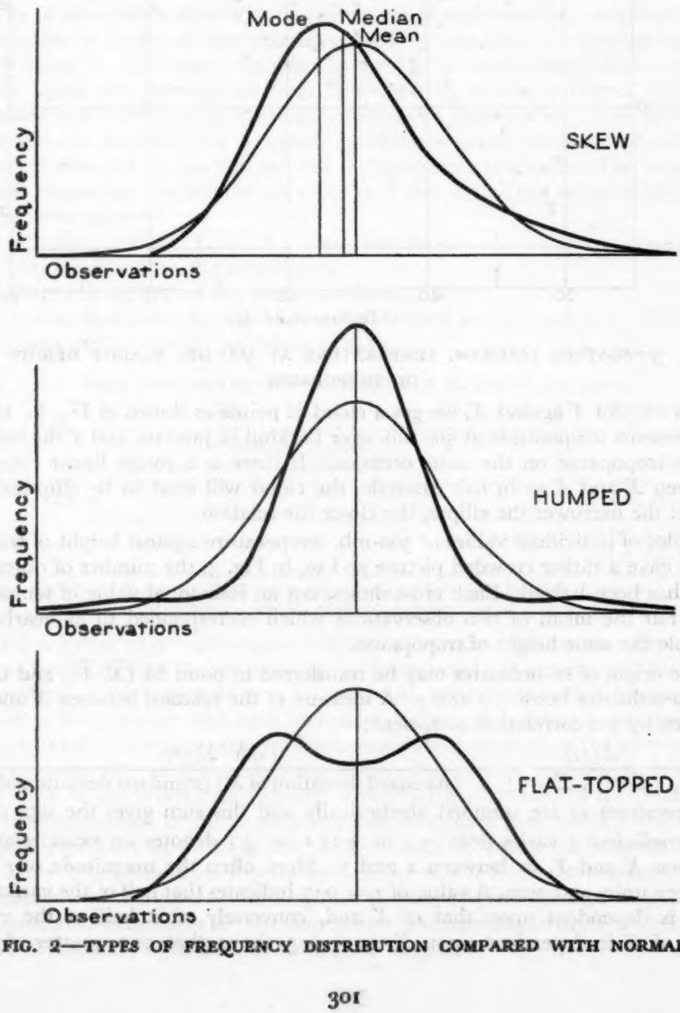


FIG. 2—TYPES OF FREQUENCY DISTRIBUTION COMPARED WITH NORMAL

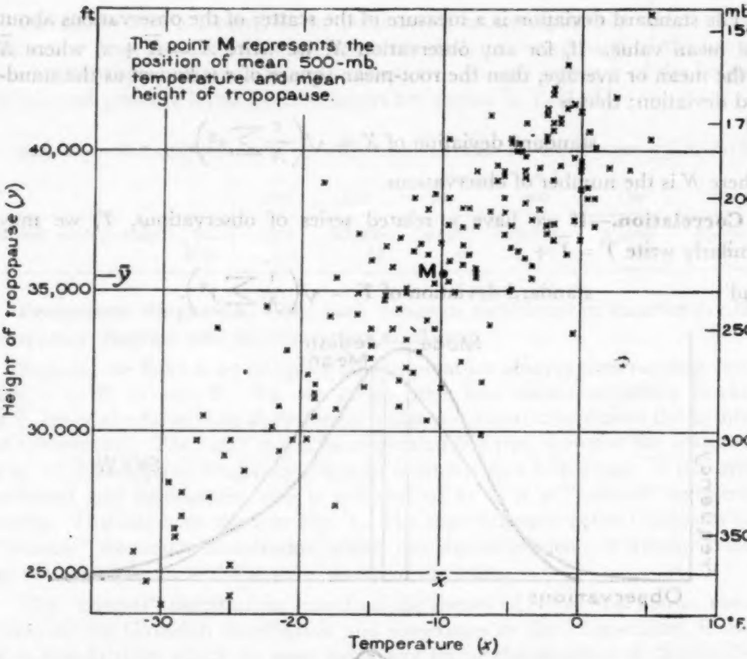


FIG. 3—SCATTER DIAGRAM. TEMPERATURE AT 500 MB. AGAINST HEIGHT OF TROPOPAUSE

When we plot Y against X, we get a cloud of points as shown in Fig. 3. Here X represents temperature at 500 mb. over Larkhill in January and Y the height of the tropopause on the same occasion. If there is a rough linear relation between X and Y as in this example, the cloud will tend to be elliptical in shape: the narrower the ellipse, the closer the relation.

A plot of individual values of 500-mb. temperature against height of tropopause gave a rather crowded picture and so, in Fig. 3, the number of observations has been halved. Each cross shows, not an individual value of temperature, but the mean of two observations which corresponded to as nearly as possible the same height of tropopause.

The origin of co-ordinates may be transferred to point M ($\bar{X}$, $\bar{Y}$), and then the co-ordinates become x and y. A measure of the relation between X and Y is given by the correlation coefficient:—

$$r = \frac{\Sigma(xy)}{\sqrt{\{\Sigma(x^2)\,.\,\Sigma(y^2)\}}} = \frac{(1/N)\Sigma(xy)}{(\text{standard deviation of } X)\ (\text{standard deviation of } Y)}$$

The products xy are summed algebraically and this sum gives the sign of r. The coefficient r varies from -1 to $+1$; $r = \pm 1$ denotes an exact relation between X and Y, or between x and y. More often the magnitude of r lies between unity and zero. A value of $r = 0 \cdot 7$ indicates that half of the variation of Y is dependent upon that of X and, conversely, that half of the variation of X is dependent upon Y; $r = 0 \cdot 5$ shows that one quarter of the

variation of Y depends upon X; and generally, we may write

$$\sigma_y^2 = r^2\sigma_y^2 + (1-r^2)\,\sigma_y^2$$

where σ_y denotes the standard deviation of Y. The term $r^2\sigma_y^2$ is closely related to the variation of X; the term $(1-r^2)\sigma_y^2$, the remaining part of σ_y^2, can be shown to be entirely independent of X.

Application to upper air work.—Frequency curves and correlation coefficients have been familiar to meteorologists during the past 50 years. The earliest reference in meteorological literature to the fitting of a normal frequency curve that the author could find is in a paper dated 1906. In this Van der Stok[1] compares a frequency polygon of 22,188 pressure values at the Helder, Holland, in January and February 1843–1904, with the equivalent normal curve. Correlation occurs at least as early as 1907 when Hooker[2] published results of his studies of relations between crops and weather. Application of correlation to upper air data comes only a few years after, the pioneer in such work being W. H. Dines. He was not the first to make systematic soundings of the upper air, although his work followed very soon after that of Rotch in America and Teisserenc de Bort and Assmann in Europe; but, as far as can be gathered, he was the first to examine relations which he detected between different elements in the free air and to test them statistically. The largest of Dines' correlation coefficients are given in Table III. They relate height (H_c) of the tropopause to

(i) temperature (T_c) at the tropopause level
(ii) conditions in the troposphere
(iii) pressure (P_s) at the earth's surface.

The values shown are from a Memoir[3] published in 1919 but they differ very little from earlier values[4] published in 1912.

TABLE III—CORRELATION COEFFICIENTS IN UPPER AIR DATA

	T_c	P_9	T_m	P_s	H_{1000}	H_{300}	T_{500}	Authority
			correlation coefficient					
H_c	−0·68	+0·84	+0·79	+0·68	...	...	...	W. H. Dines
H_c	−0·47	...	...	...	+0·49	...	...	C. H. B. Priestley
P_c	...	...	...	...	...	−0·75	−0·75	J. K. Bannon and A. Gilchrist

Data used: Dines, European, 1902–13, scattered days; Priestley, Larkhill, 1944, all months; Bannon and Gilchrist, Larkhill, 1948–50, January, April, July and October.

The negative relation between height and temperature at the tropopause shown by the first coefficient listed, is not unexpected. It arises partly from the conception of the troposphere as a layer of atmosphere in which temperature falls at a fairly steady rate with increasing height: the higher the tropopause the greater the fall in temperature from near-surface air to air at the tropopause. The pressure (P_9) at 9 Km. and the mean (T_m) of temperatures at 2·5, 5·0 and 7·5 Km. are related very closely. Dines[3] writes, "Whatever the reason for the curious division of the atmosphere into two parts may be, it is the value of the air pressure at about 9 Km. height which regulates the position of the boundary"; but nowadays it is thought rather that it is the temperature of the troposphere which governs the height of the tropopause; for high tropopauses are associated with warm air, the tropopause in temperate latitudes being higher in air of tropical origin than in air of polar origin.

The coefficient relating height of tropopause with surface pressure (P_s) is consistent with the study of depressions and anticyclones by later workers who find that the tropopause tends to be lower than average over depressions and higher than average over anticyclones.

Dines' results are confirmed numerically by Priestley[5] and by Bannon and Gilchrist[6] (Table III). Priestley uses height (H_{1000}) of the 1000-mb. level instead of surface pressure; Bannon and Gilchrist, instead of height of tropopause worked with the pressure (P_c) at the tropopause, correlating this with height (H_{300}) of the 300-mb. level and with temperature (T_{500}) at 500 mb. The last is shown by both Dines and Priestley to give a good approximation to the mean temperature of the troposphere. The coefficients given by Bannon and Gilchrist are much nearer in magnitude to those of Dines than are Priestley's, but Priestley's are computed from only one year's observations.

Perhaps the chief value of the work by Bannon and Gilchrist[6] is that it covers a variety of latitudes, the following stations being examined:

			Period
Arctic Bay	73°N.	84°W.	1948–50
Lerwick	60°N.	1°W.	1948–50
Larkhill	51°N.	2°W.	1948–50
Malta	34°N.	14°E.	1948–51

For Arctic Bay in July, for Lerwick, for Larkhill in January, April and October and for Malta in January and April, the correlation coefficients are very much of the same order as the mean values shown for Larkhill. The values for Larkhill in July and for Arctic Bay in other months are rather lower and those for Malta in July and October very much lower; in fact those for Malta in July are too small to be significant.

Frequency distributions of temperature.—The form of the relation between any two elements correlated can be gathered from the pattern exhibited by their combined frequencies; but, before considering this, it seems logical to discuss more fully the frequency distributions characteristic of a single element, upper air temperature.

A detailed picture of variations in upper air temperature can be gleaned from recent publications of radio-sonde data for stations in the British Isles and the Middle East[7] by the Meteorological Office. Each of these publications includes histograms for the four mid-season months, January, April, July and October at the pressure levels 700, 500, 300, 200, 150 and 100 mb. For the most part, the frequency distributions portrayed do not appear to deviate much from the "normal"; but, at 200 mb. over stations north of 33°N. in January and April, there is a marked widening of the range of temperature accompanied by a flattening of the histograms (see Fig. 2). At Larkhill (51°N.), these seem to be bi-modal, i.e. there are two temperature values at which the frequency rises to a maximum. Examples of the two salient types of histogram of upper air temperature are given in Figs. 1 and 4, with empirical curves superimposed. The "normal" curve of Fig. 1 was described earlier. The histogram in Fig. 4 shows frequencies of temperature at 200 mb. over Larkhill during the winter months December to January; and to these data is fitted the sum of two normal frequency curves. These correspond to two different régimes

[*To face p.* 304

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HAILSTONES AT TUNBRIDGE WELLS

(see p. 298)

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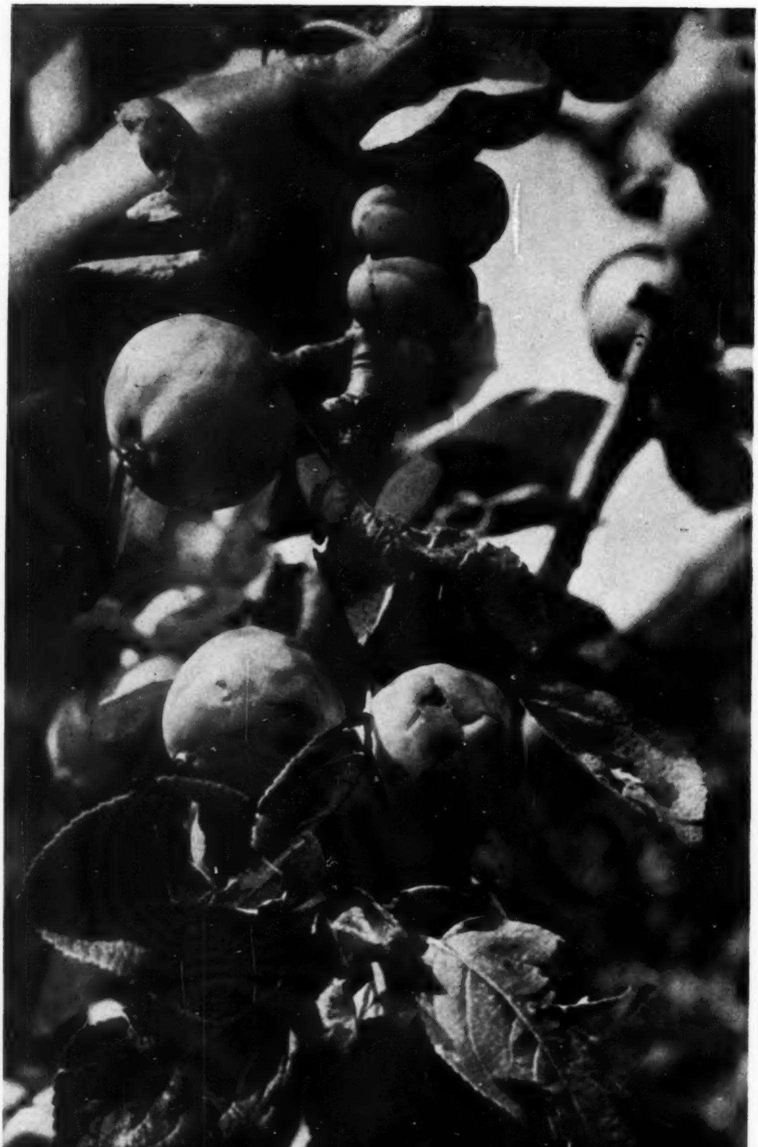
THE DIRECTOR OF THE METEOROLOGICAL OFFICE AT THE ITINERANT METEOROLOGICAL EXHIBITION AT LEICESTER, AUGUST 3, 1956

The Lord Mayor of Leicester and a member of the Leicester City Council are on the Director's right

(see p. 314)

ITINERANT METEOROLOGICAL EXHIBITION DISPLAYED IN LEICESTER MUSEUM, AUGUST 3–26, 1956

(see p. 314)



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APPLES DAMAGED AND LEAVES TORN BY HAILSTONES

(see p. 299)

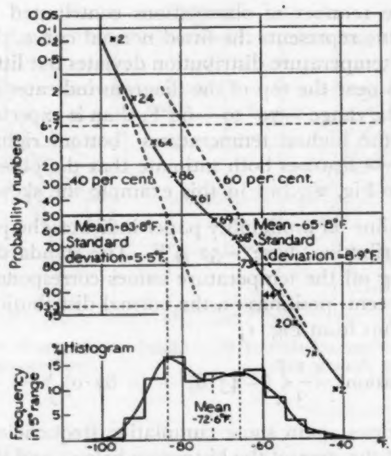


FIG. 4—TEMPERATURE AT 200 MB., LARKHILL, DECEMBER–FEBRUARY 1942–44
Number of observations = 520

of temperature; the left-hand curve, with mode at $-84°$F., appears to correspond to temperature of air within the troposphere or very near the tropopause, that on the right, with mode at $-66°$F., to stratospheric air. The method of fitting is by means of "probability" paper.

Probability paper.—This is a special type of graph paper. The coordinates are rectangular; one scale is linear and the other is the probability scale. Fig. 5 shows a normal distribution of frequencies; the shaded portion under the frequency curve to the left of X, represents the total frequency of values of observations which are less than the value X. In plotting such a frequency distribution on probability paper, the value X is taken as abscisse along the linear scale; and the corresponding percentage cumulative frequency, i.e. the shaded portion of Fig. 5, expressed as a percentage of the whole area under the curve, is taken as ordinate along the probability scale. This scale is so designed that if the frequency distribution is exactly normal, then the plotted points all lie exactly along a straight line. The ordinate may be termed the "probability number". Hints on plotting were given in an earlier article[8].

The probability-plot of a frequency distribution which is nearly normal is given in Fig. 1. The crosses represent the cumulative frequencies corresponding to the middle points of the steps of the histogram shown below, and the small

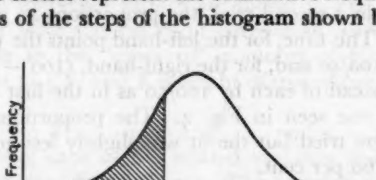


FIG. 5—NORMAL FREQUENCY DISTRIBUTION
The shaded portion is the cumulative frequency corresponding to the value X

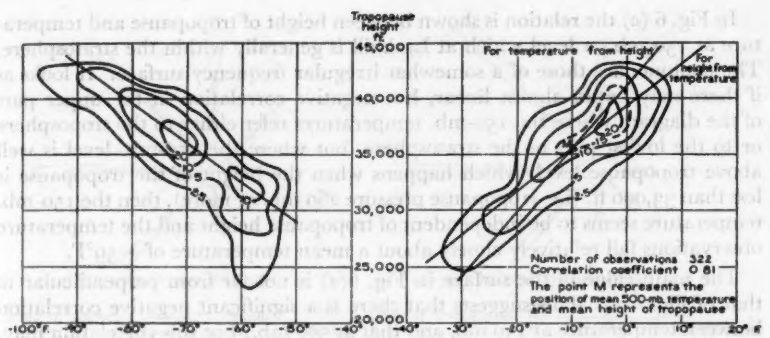
figures indicate the number of observations contributed by each successive step; the straight line represents the fitted normal curve. It will be seen that the actual 300-mb. temperature distribution deviates but little from the straight line. The steepness near the top of the diagram indicates a greater clustering of observations in the range $-70°$ to $-60°$F. than is expected from the normal distribution; also, the highest temperatures (bottom right-hand corner) are more extreme. These features both intimate that the observed distribution is positively skew (see Fig. 2), but in this example the skewness is only slight.

The 50 per cent. line on probability paper indicates the position of the mean on the normal distribution, here $-52 \cdot 9°$F. The standard deviation may be obtained by reading off the temperature values corresponding to the $6 \cdot 7$ per cent. and $93 \cdot 3$ per cent. positions on the normal distribution and dividing the difference by 3. Thus from Fig. 1,

$$\text{standard deviation} = \frac{1}{3}\left\{(-43 \cdot 8) - (-62 \cdot 0)\right\} = \frac{18 \cdot 2}{3} = 6 \cdot 1°\text{F.}$$

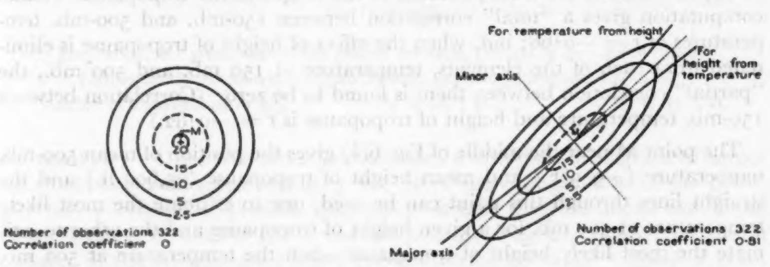
In Fig. 4 the crosses again show cumulative frequencies corresponding to the middle points of the steps of the histogram below; and the full line through the crosses represents the same compound distribution as is shown by the curve superimposed on the histogram. The curve was fitted by a very simple method given by Harding[9]. The crux of his method lies in estimating the proportion of the total frequency to be assigned to each component "normal" distribution. A first shot is made by judging the point of inflexion of a curve drawn by eye through the plotted points; and the division which gives the best fit is then determined by further "trial and error". For the data of Fig. 4, the point of inflexion appeared to be not far from the 50-per-cent. line and so, to begin with, it was supposed that half the frequencies should be allocated to each component. The two components are determined from the tails of the total distribution. The four points nearest the top of Fig. 4 were replotted with their probability numbers doubled and a straight line was drawn by eye as nearly as possible through the new points. This represented one normal component distribution. The six points nearest the right-hand side were replotted with $(100 - P)$ doubled, P being the probability number, and a straight line through these new points gave a first shot at the second component distribution. When these two 50-per-cent. distributions were combined, half weight being given to each, the resulting compound distribution appeared on the probability paper similar to the full line shown in Fig. 4; but, near the centre, the line representing the sum of the 50-per-cent. distributions lay slightly to the left of all the plotted crosses. This suggested that too much weight had been given to the left-hand component, and so, in a second trial, the proportions 40 per cent. and 60 per cent. were adopted. This time, for the left-hand points the probability numbers were multiplied by 100/40 and, for the right-hand, $(100 - P)$ had to be multiplied by 100/60—instead of each by 100/50 as in the first trial. The resulting combination is the one seen in Fig. 4. The proportions 35 per cent. and 65 per cent. also were tried but the fit was slightly less good than that given by 40 per cent. and 60 per cent.

Correlation surfaces.—After this interlude on linear frequency distributions and probability paper, we return to the discussion of correlated elements. The data from which Fig. 3 was derived are shown in a different manner in



(*a*) **Correlation surface of tropopause height with 150-mb. temperature**

(*b*) **Correlation surface of tropopause height with 500-mb. temperature**



(*c*) **Normal circular frequency surface.**

(*d*) **Normal correlation surface**

FIG. 6—CONTOURS OF FREQUENCY SURFACES, LARKHILL, JANUARY 1948–50

Frequencies are given for 4°F. of temperature by 2,000 ft. of height

Fig. 6(*b*). The roughly elliptical lines are contours of a frequency surface vertical sections of which are not unlike the curves fitted to the histograms in Figs. 1 and 4. The figure labelling each contour gives the actual number of observations contained in a cell representing 4°F. of temperature at 500 mb. by 2,000 ft. of height of tropopause, the contours having been slightly smoothed in the drawing.

A surface which shows the distribution of frequencies of two related variables is known as a "correlation" surface. If all vertical sections of the surface are normal frequency curves, then it is a "normal" correlation surface. Contours of such an idealized frequency surface are shown in Fig. 6(*d*). This diagram has been computed from the values of correlation coefficient and standard deviation pertaining to the "observed" contours of 6(*b*). If X is 500-mb. temperature in units of 4°F. and Y is height of tropopause in units of 2,000 ft., then

$$r = +0\cdot81, \qquad \sigma_x = 2\cdot33, \qquad \text{and } \sigma_y = 2\cdot14.$$

In normal correlation, each of the related variables is normally distributed and the relation between them is linear. The correlation between the height of tropopause and the 500-mb. temperature is seen, from Figs. 3 and 6, to be roughly linear but the frequency distributions both of height of tropopause and of temperature at 500 mb. are decidedly skew.

In Fig. 6 (*a*) the relation is shown between height of tropopause and temperature at 150 mb., a level which at Larkhill is generally within the stratosphere. The contours are those of a somewhat irregular frequency surface. It looks as if there may be an almost linear, but negative correlation in the upper part of the diagram where the 150-mb. temperatures refer either to the troposphere or to the lowest part of the stratosphere, but where the 150-mb. level is well above tropopause level, which happens when the height of the tropopause is less than 33,000 ft. (i.e. tropopause pressure 260 mb. or more), then the 150-mb. temperature seems to be independent of tropopause height and the temperature observations fall relatively closely about a mean temperature of −59°F.

The main ridge of the surface in Fig. 6(*a*) is not far from perpendicular to that of Fig. 6(*b*). This suggests that there is a significant negative correlation between temperature at 150 mb. and that at 500 mb.; but this correlation may, of course, be due chiefly to the fact that both temperature at 150 mb. and 500 mb., in opposite senses, are closely related to the height of the tropopause. Actual computation gives a "total" correlation between 150-mb. and 500-mb. temperatures of $r = -0{\cdot}66$; but, when the effect of height of tropopause is eliminated from each of the elements, temperature at 150 mb. and 500 mb., the "partial" correlation between them is found to be zero. (Correlation between 150-mb. temperature and height of tropopause is $r = -0{\cdot}82$.)

The point M near the middle of Fig. 6(*b*) gives the position of mean 500-mb. temperature (−9·9°F.) and mean height of tropopause (35,600 ft.) and the straight lines through this point can be used, one to estimate the most likely temperature at 500 mb. for a given height of tropopause and the other to estimate the most likely height of tropopause when the temperature at 500 mb. is known. These two lines are misnamed "regression" lines. The term "regression" was introduced (*circa* 1886) in a problem on heredity studied by Sir Francis Galton and the term has persisted generally. Papers by Galton are cited by Yule and Kendall[10]. The regression lines are distinct from one another so long as the correlation is not unity; they are more and more divergent the nearer r approaches zero, being parallel to the axes of X and Y when the correlation between them is zero; but they coincide when $r = \pm 1$. Formulae for the regression lines are derived in most textbooks of statistics.

The normal correlation surface shown in Fig. 6(*d*) may be regarded as a smoothed and simplified form of Fig. 6(*b*). In Fig. 6(*c*) the contours have been smoothed to an even greater extent; this diagram shows the normal frequency surface that would result if the correlation were zero and the standard deviations of X and Y were equal. All the contours are circles. Such a circular distribution is believed to be characteristic of homogeneous collections of winds in the upper air.

Wind.—The elements considered up to now, temperature, pressure and height, have been scalar quantities. Wind, being a vector (i.e. a quantity having direction as well as magnitude) requires a somewhat different treatment. Any vector can be resolved uniquely into components in three fixed directions mutually at right angles; in a statistical examination of winds, however, the vertical component may be neglected and thus any wind observation is considered as the resultant of two horizontal components each of which can be treated as a scalar element. This means that winds may be plotted in a correlation diagram like that of Fig. 3, X being the easterly component and Y

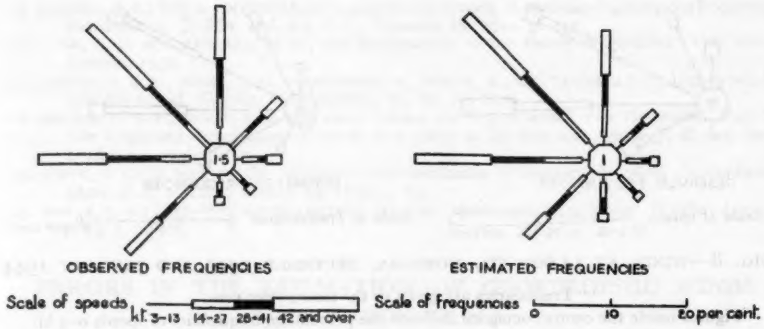


FIG. 7—WINDS AT 500 MB., LARKHILL, DECEMBER–FEBRUARY 1939–40 TO 1944–45

Frequencies are given only to the nearest per cent. (except in the case of calms)
Figures inside the central octagons indicate percentage frequency of calms
Number of observations = 483 V_R = 18·1 kt. V_s = 37·6 kt.

the northerly. The main difference between a correlation diagram of upper air winds and that given as Fig. 3 will be in the configuration of the points plotted. Whereas the present temperature-height diagram shows something of an elongated ellipse, the wind-components diagram might be almost circular in shape with the plotted points distributed radially about a point representing the vector mean wind.

Actual examination of homogeneous sets of observations of winds in the upper air confirmed three important characteristics: first, the easterly and the northerly components are "normally" distributed; secondly, there is no appreciable correlation between these components; and, thirdly, their standard deviations are equal. This meant that the winds examined did in fact conform to normal circular frequency distributions, such as that illustrated in Fig. 6(*c*). (This will not often be true of winds within about 1,000 ft. of the earth's surface; nor is it true of winds at higher levels unless they are strictly homogeneous. For example, Scott[13] finds that a distribution comprising winds throughout September, October and November at 50,000 ft. above Singapore is strongly elliptical; but other evidence, for example Hay[14], suggests that these winds are not confined to a single régime.)

The closeness with which the empirical model fits the actual observations may be gathered from Figs. 7 and 8, reproduced from a Memoir by C. E. P. Brooks and others[11]. Here the data are in the form of wind roses and so the centre of the circular distribution lies not in the central octagon but at a distance from it representing (on the scale of speeds) the magnitude of the vector mean wind. The parameters used in computing the "estimated" frequencies were the direction of the vector mean and its magnitude (V_R), the average speed (V_S) and the number of observations. Details of computation are given in the Memoir[11].

One advantage of the agreement between the simple normal circular frequency surface and actual distributions of upper air winds is that components

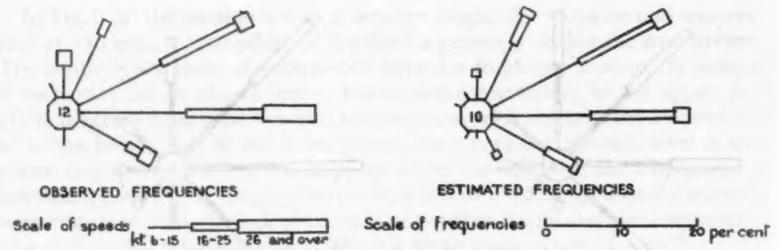


FIG. 8—WINDS AT 14,000 FT., MOMBASA, DECEMBER 1943 AND JANUARY 1944

Frequencies are given to the nearest per cent.
Figures inside the central octagons indicate the percentage frequencies of speeds 0–5 kt.
Number of observations = 52 $V_R = 7{\cdot}6$ kt. $V_s = 14{\cdot}1$ kt.

in any specified direction may be assumed to be distributed normally and so probability paper again is of use in making further deductions, (see Goldie[8]).

Practical applications.—Where frequency distributions of temperature or of wind have been shown to be "normal" this fact has, in a number of instances, been applied to practical problems.

One illustration may suffice. A normal circular wind rose can be computed where the only data available are the vector mean wind and the average wind speed, or even where there are no wind data at all so long as estimates of the vector mean wind and of some measure of the scatter of individual winds about it are possible. The computed wind rose can then be used to estimate probabilities of high winds in specified directions. This is the sort of information that was continually being asked of the Meteorological Office, as far back as the beginning of 1945, in connexion with the planning of post-war civil air routes; and it was this that prompted, first, an investigation into frequency distributions of upper winds[12] and later, the charting of the necessary parameters (estimated where necessary) for the greater part of the globe[11].

The tropopause height used is not an exact height but is the result of converting actual values of pressure at the tropopause to a height scale based upon the average heights (1946–50) of the principal isobaric surfaces.

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ERRORS IN THE ESTIMATION OF GEOSTROPHIC WINDS

By A. F. CROSSLEY, M.A.

A method is described of computing the standard error in the estimation of geostrophic winds from given charts of isobars or pressure contours and an application is made to 500-mb. contour charts.

Theory.—In geostrophic motion the equation of continuity, apart from a small effect due to variations in density which will be ignored, is

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \quad \ldots\ldots (1)$$

where u and v will be regarded as the components of geostrophic wind from W. and S. respectively. If true values of components of the gradient of the geostrophic wind could be obtained from a series of charts, the correlation coefficient between $\partial u/\partial x$ and $\partial v/\partial y$ would have the value -1, so that

$$R=\frac{\overline{\dfrac{\partial u}{\partial x}\,\dfrac{\partial v}{\partial y}}}{\sqrt{\left\{\overline{\left(\dfrac{\partial u}{\partial x}\right)^2}\;\overline{\left(\dfrac{\partial v}{\partial y}\right)^2}\right\}}}=-1, \quad \ldots\ldots (2)$$

where a bar denotes a mean value. Now suppose the gradients are replaced by differences at finite intervals which are the same in all cases. If the geostrophic winds refer to four fixed points A, B, C, D equidistant from a central point and bearing north, south, west and east respectively, then equation (2) may be written

$$R=\frac{\overline{(u_D-u_C)\,(v_A-v_B)}}{\sqrt{\{\overline{(u_D-u_C)^2}\;\overline{(v_A-v_B)^2}\}}}=-1. \quad \ldots\ldots (3)$$

The result of inserting estimated components of wind (denoted by primes) in equation (3) is to give

$$R'=\frac{\overline{(u'_D-u'_C)\,(v'_A-v'_B)}}{\sqrt{\{\overline{(u'_D-u'_C)^2}\,\overline{(v'_A-v'_B)^2}\}}} \quad \ldots\ldots (4)$$

in which the value of R' will be numerically less than unity. The relations between the estimated and true geostrophic components are written as

$$\left.\begin{aligned}u'_D&=u_D+\varepsilon_D, & u'_C&=u_C+\varepsilon_C,\\ v'_A&=v_A+\varepsilon_A, & v'_B&=v_B+\varepsilon_B,\end{aligned}\right\} \quad \ldots\ldots (5)$$

where the ε's are the errors in the estimated components. These errors are not expected to be correlated with the geostrophic components and if the space intervals used are sufficiently large, then the errors would not be correlated with each other. In their work on electronic computation of thickness charts, etc., Bushby and Hinds[1] use a grid length of about 140 n. miles; an interval of this order appears adequate to ensure mutually independent errors. With these assumptions it is easy to deduce from equation (5) that

$$\left.\begin{aligned} \overline{(u'_D-u'_C)(v'_A-v'_B)} &= \overline{(u_D-u_C)(v_A-v_B)}, \\ \overline{(u'_D-u'_C)^2} &= \overline{(u_D-u_C)^2} + \overline{\varepsilon_D^2} + \overline{\varepsilon_C^2}, \\ \text{and} \qquad \overline{(v'_A-v'_B)^2} &= \overline{(v_A-v_B)^2} + \overline{\varepsilon_A^2} + \overline{\varepsilon_B^2}. \end{aligned}\right\} \quad \ldots (6)$$

Further there seems no reason to expect the mean square errors to differ significantly among themselves provided the number of observations is sufficiently large and provided there is no large gradient of mean wind across the grid of points A, B, C, D. The latter was investigated and found to be small. The suffixes may therefore be omitted from the mean square errors. Then from equations (3), (4) and (6) we obtain

$$R' = R\bigg/\sqrt{\left\{1 - \frac{2\overline{\varepsilon^2}}{\overline{(u'_D-u'_C)^2}}\right\}}\bigg/\sqrt{\left\{1 - \frac{2\overline{\varepsilon^2}}{\overline{(v'_A-v'_B)^2}}\right\}}$$

$$= R(1 - 2\,\overline{\varepsilon^2}/a^2)$$

approximately, where

$$\frac{1}{a^2} = \frac{1}{2}\left\{\frac{1}{\overline{(u'_D-u'_C)^2}} + \frac{1}{\overline{(v'_A-v'_B)^2}}\right\} \quad \ldots\ldots (7)$$

so that

$$\overline{\varepsilon^2} = \tfrac{1}{2}a^2(1 - R'/R). \quad \ldots\ldots (8)$$

Putting R equal to -1, this becomes

$$\overline{\varepsilon^2} = \tfrac{1}{2}a^2(1 + R'). \quad \ldots\ldots (9)$$

whence the standard vector error is

$$\sigma_e = a\sqrt{(1 + R')}. \quad \ldots\ldots (10)$$

It is to be remarked that the approximations involved in disregarding variations of density, equation (1), and in using finite differences, equation (3), both tend to decrease the numerical value of R. If a value of R slightly less numerically than unity is used in equation (8) then the computed value of $\overline{\varepsilon^2}$ is decreased. Thus the value of $\overline{\varepsilon^2}$ and hence of σ_e corresponding to $R = -1$ should be regarded as an upper limit to the true value.

Application.—Measurements of the geostrophic wind were made at four points over England and the North Sea, namely at A and B on the Greenwich meridian at 55½°N. and 51½°N. respectively, and at C and D on latitude 53½°N. and longitudes 3½°W. and 3½°E. respectively. The half-distance between each pair of points is 120 n. miles. Working charts of 500-mb. contours were used for December 1954, January and February 1955 at 0300 G.M.T. and 1500 G.M.T. each day, a total of 180 charts. In order to ensure that the measurements were unbiased by plotted reports of observed winds, tracings of the original contours were used. The results of the computations based on these measurements are given in Table I.

For the three months taken together, the computed correlation coefficiens (R') between the measured geostrophic gradients is $-0 \cdot 85$. Confidence limitt for R' at the 5 per cent. level of significance were computed by means of Fisher's z' transformation[2]. The root-mean-square vector error (σ_e) of the estimations of geostrophic wind is found to be 5 kt. for an average wind speed of 39 kt. This result may be compared with one obtained by Murray[3] by quite a different method. Two analysts made measurements of the geostrophic wind independently on the same series of charts and the differences in the results indicated a value of σ_e of about 6 kt. Both the number, N, of pairs of measurements and the mean wind speed were almost identical with those of the present investigation. The "standard error" of either value of σ_e, given by $\sigma_e/\sqrt{(2N)}$, is 0·3 kt. The good agreement between the present estimate and Murray's suggests that no appreciable correction is required on account of the approximations used, for it has already been remarked that any correction could only decrease the value of σ_e and so increase the difference from Murray's figure. An application of "Student's" t test shows that the two values of σ_e are not significantly different. Hence if the two methods are given equal weight, the best estimate of the standard vector error of estimation of geostrophic wind is 5½ kt. for a mean speed of 40 kt.

It is to be expected that the error should tend broadly to increase with the wind speed. As the mean speed at the four points decreased from 49 kt. in December 1954 to 36 kt. in January 1955 and 29 kt. in February 1955, the value of the error was also determined for each month separately. Although the February figure is the smallest and corresponds with the lighest winds, the figures for the other two months come out equal and the evidence for increase of error with speed cannot be regarded as significant on the data available.

TABLE I—ERRORS OF ESTIMATION OF GEOSTROPHIC WIND

	December 1954	January 1955	February 1955	3 months
Number of charts, N	62	62	56	180
Correlation coefficient, R'	−0·86	−0·80	−0·89	−0·85
5 per cent. limits of R'	−0·92, −0·78	−0·87, −0·68	−0·94, −0·82	−0·89, −0·81
		knots		
Measure of wind differences, a	14·3	11·8	12·7	13·3
Standard vector error of estimation, σ_e	5·3	5·3	4·2	5·1
Standard error of σ_e	0·5	0·5	0·4	0·3
Mean scalar speed	49	36	29	39

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2. BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953.
3. MURRAY, R.; On the accuracy of contour charts in forecasting upper winds. *Prof. Notes Met. Off., London*, **7**, No. 110, 1954.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

GEOPHYSICAL MEMOIRS

No. 95.—*Wind and temperature to* 50 *Km. over England. Anomalous sound-propagation experiments, 1944–45*. By R. J. Murgatroyd, B.Sc. (Eng.).

This report describes the results of experiments made in England during 1944–45, when recordings of sound received by anomalous paths from large explosions were utilized in an attempt to obtain data on wind and temperature at great heights. The methods used and their limitations are outlined and the results of the calculations presented. The principal results are:—

(i) In England the wind in winter at heights of 30–45 Km. is usually between SW. and NW. with speeds of 40–80 m./sec. In summer the directions are between NE. and SE. and the speeds less than 20 m./sec.

(ii) The temperature between 35 and 50 Km. appears to increase to values approaching surface values. This increase is not as great in winter as in summer, and a 20–40°C. variation of temperature between summer and winter is likely at these levels.

LETTER TO THE EDITOR

Paraselenae

On Sunday, May 20, 1956 at 2354 G.M.T. paraselenae were observed from Acklington, Northumberland. Both mock moons were white in colour and situated at approximately 22° horizontally on either side of the moon, but there was no halo. Visibility was 10 miles. There was almost complete cover of thin cirrostratus with about 5 oktas of stratocumulus at 3,500 ft.

This phenomenon occurred on the same day as a period of solar halos and parhelia, lasting from 0827 G.M.T. to 0954 G.M.T. Parhelia, similar to those shown in the photograph on page 136 of the *Meteorological Magazine* for May 1956, were observed from 0627 G.M.T. to 0754 G.M.T. During this period, visibility was over 15 miles and the cloud increased from 4 to 7 oktas of thin cirrus.

Acklington, Morpeth, Northumberland, May 21, 1956.

W. J. STEWART

[The absence of a halo indicates the refracting edges of the ice crystals were predominantly vertical.—Ed., M.M.]

NOTES AND NEWS

Itinerant Meteorological Exhibition

The first display of the Itinerant Meteorological Exhibition for Museums was opened by Sir Graham Sutton at Leicester Museums and Art Gallery on August 3, 1956 in the presence of the Lord Mayor of Leicester and an invited audience.

The exhibition at Leicester (see photographs in centre of this Magazine) was the first of a series which has been planned to visit museums in the north Midlands and later, museums in other areas. The displays will remain open to the public for periods varying from four to eight weeks at each town or city before travelling on to the next. This should provide opportunity for townsmen and citizens to acquaint themselves at their leisure with its contents i.e. everyday instruments and equipment for observational work, diagrams and photographs describing observations, a complete set of working charts for one day from the Central Forecasting Office, a series of large panels showing how the work of the Meteorological Office enters into the daily life of the community and, for those Museums with the proper outdoor space, a working instrument enclosure.

The idea of this travelling exhibition originated partly with the Centenary Forecast Display of 1955 which visited the six largest cities of the United Kingdom and partly with a meteorological display which was concurrently exhibited in Derby Museum. The popularity of the exhibit at Derby, arousing as it did the interest of other museums, suggested a way of reaching other areas. So the Meteorological Office in conjunction with Air Ministry Information Division built a new display, specially suited to Museums, using much of the existing material from the two previous exhibitions. With the assistance of the Keeper in Geology at Leicester Museums and Art Gallery an itinerary was then arranged which has subsequently developed into a tour that so far, will be continuous till July 1957. If the total of 16,091 visitors to the Leicester Museum in three weeks is any guide to the value of this Meteorological Exhibition it should have a useful life.

W. R. HANSON

International cloud atlas

Readers will be pleased to learn that the new "International cloud atlas" is now being published by the World Meteorological Organization. The atlas will be available in the following volumes:

	Title	Expected date of issue
(1)	INTERNATIONAL CLOUD ATLAS—COMPLETE (in two volumes)	
	Volume I } these two volumes	Autumn 1956
	Volume II } are sold separately	August 1956
(2)	INTERNATIONAL CLOUD ATLAS—ABRIDGED ATLAS	Autumn 1956
(3)	INTERNATIONAL CLOUD ATLAS—ALBUM	End of 1956
(4)	INTERNATIONAL CLOUD ATLAS—BARE PLATES OF VOLUME II	August 1956
(5)	INTERNATIONAL CLOUD ATLAS—BARE PLATES OF THE ABRIDGED ATLAS	Autumn 1956
(6)	INTERNATIONAL CLOUD ATLAS—BARE PLATES OF THE ALBUM	End of 1956

Volume I of the "International cloud atlas" contains a detailed descriptive study of clouds and "meteors" and Volume II contains 224 plates, 103 of which are in colour, to illustrate the text of Volume I. The "Abridged atlas" contains 72 plates and the "Album", which is specially intended for the use of pilots and airborne observers, 32 plates.

A detailed prospectus of the atlas can be obtained on application to the World Meteorological Organization, Campagne Rigot, Avenue de la Paix, Geneva, Switzerland.

REVIEW

Weather analysis and forecasting. 2nd edn. Volume I. Motion and motion systems. By S. Petterssen. 9¼ in. × 6⅛ in., xx + 428, *Illus.* McGraw-Hill Book Co. Inc., New York, Toronto and London, 1956. Price 64*s*.

The first edition of "Weather analysis and forecasting" described the state of forecasting knowledge at the outbreak of the Second World War. In its preface we read that "recent advances . . . have led to actual application of the principles of physics and mathematics in the forecasting of weather". That statement, more than the date of publication, reminds us of the progress that has been made since 1940. The author, anticipating the question of why so many years separate the second edition from the first, writes in his new preface that "progress in meteorological research has been so rapid that it has not been possible to provide a reasonably stable revision at an earlier date". While Dr. Petterssen considers past achievements to be adequately consolidated he gives no indication that he recognizes any flattening in the curve of progress. On both counts a textbook of this kind fulfils a major requirement, and meteorologists will welcome this most lucid and readable manual.

At the time of writing only the first of the two volumes of "Weather analysis and forecasting" has been published, but the other is expected shortly. This first volume is about as long as the complete first edition of the book. Its subtitle is "Motion and motion systems" and it deals with the dynamics of atmospheric processes. Volume II, called "Weather and weather systems" places the emphasis on thermodynamics and will include weather features associated with smaller-scale atmospheric movements.

By way of introduction, Dr. Petterssen makes an interesting comment on the role of the forecaster when machine-made forecasts are in regular use. He makes the point that the computed prognosis must fall short by an "unexplained residual" because it works on idealized models. It is for the forecaster to remedy this weakness, using theoretical knowledge and the insight that comes from experience, both of which must be maintained at a high level. This function is additional to the essential daily task of translating into a forecast the output of the machine. Dr. Petterssen has set out to provide a text for the training that is required, and in doing so he aims to reduce the gap between synoptic and dynamic meteorology.

The first half of the first edition dealt largely with air-mass features. In so far as the two editions can be related, the second begins half-way through the first. An opening chapter on basic equations is followed by kinematics of quasi-horizontal motion. Chapter 3, kinematics of the pressure field, is based (like most of Chapter IX in the first edition) on the author's papers of 1933 on the movement of surface isobaric systems. A section is included extending the method to forecasting the intensification of pressure centres, but it concludes with a warning that this approach, being based on extrapolation of the instantaneous pressure and tendency fields is not recommended except for changes over short periods.

Chapter 5 remedies a curious omission from the earlier edition by providing a brief account of the influence of surface friction. This perhaps foreshadows the consideration of frictional effects not mainly as by-products of the existing flow but as factors imposing calculable modifications on the circulation.

It is something of a surprise to discover that Chapter 6, on the vertical structure of wind systems, had no counterpart in the earlier edition, until one recalls that only 15 years ago there was no network of upper air stations, and the existence of jet streams was a matter for little more than speculation, supported mainly by the mean distribution of upper air temperature. The next four chapters, too, are new, for they deal with vorticity applications and long-wave theory from the development of the basic Rossby formula up to the present time. Excellent examples are given showing the extent to which these and other methods can be used to estimate the movement of pressure systems.

Some similarity to the first edition appears in Chapters 11–13, which deal with frontogenesis and the structure and behaviour of cyclones and anti-cyclones. There is, nevertheless, much new material, as is indicated by the fact that 35 of the 41 references at the end of Chapter 13 refer to post-war publications.

Dr. Eliassen has written Chapter 15, on instability theories of cyclone formation. This reviews the work on wave development in an air stream which results from the existence of vertical and horizontal gradients of wind speed.

Next, the development of cyclones (with passing reference to the difficulty of assessing anticyclonic development) is dealt with on Sutcliffe lines. Synoptic examples include that of the hurricane "Hazel" of October 1954, whose redevelopment and acceleration when over the eastern United States appear to have been forecast with marked success.

Dr. Eliassen contributes a further chapter in introducing the subject of numerical forecasting and includes a detailed account of the computation process for the barotropic model. Dr. Petterssen follows this with a description of the graphical method of Fjörtoft, as well as that of Estoque, which, with substantial simplifications, treats graphically both the 500-mb. and the 1000–500-mb. thickness patterns. The concluding remarks of Dr. Petterssen, written after the publication of Fjörtoft's extension of his theory to the baroclinic model, are of particular interest at a time when the function of objective methods is a matter for speculation among forecasters. The author writes as follows: "It is foreseeable, therefore, that graphical integrations based on the more complete treatment by Fjörtoft will become a mainstay in the forecasting of motion systems. While none of the models proposed for numerical or graphical integration has been tested extensively, it is foreseeable that no single model will be capable of giving satisfactory results in all cases, and it is likely that a family of models will be needed. In each case the choice, based upon experience, must be made."

The arrangement of the book is clear-cut, and the cross-references in the text are particularly helpful in showing the basis for statements which depend on what has gone before. The diagrams and general presentation are of the high standard one is accustomed to in McGraw-Hill publications. The reader who hesitates over the cost should bear in mind that after reading the first volume he is certain to want to possess the second.

C. J. BOYDEN

OBITUARY

Mr. Thomas Lawrence Arthur Waite.—It is with deep regret that we learn of the sudden death on July 22, of Mr. Waite at the age of 39.

Mr. Waite joined the Office in January 1940 as a Meteorological Assistant, but he was reappointed a Temporary Forecaster II in April 1940. After a course at the Training School he was posted to an aviation outstation and, apart for a period in 1947 at radio-sonde units and in 1949–50 in an ocean weather ship, he has been mainly concerned with forecasting for the Royal Air Force. At the time of his death he was serving at Watnall.

He is survived by a widow and a son and daughter to whom the sympathy of all who knew him in the Office is extended.

METEOROLOGICAL OFFICE NEWS

Retirements.—*Mr. D. F. Bowering, M.B.E.*, Senior Experimental Officer, retired on August 31, 1956. He joined the Office as a Staff Assistant in January 1920 after service in the Royal Naval Air Service and the Meteorological Section, Royal Air Force during the First World War. Apart from a period between 1927 and 1931 in the Forecast Division at Headquarters, the whole of his 37 years' service has been spent at aviation outstations, including a tour of duty in Iraq. Since 1947, until his retirement, he has been the

officer-in-charge of the Meteorological Office at Croydon Airport. He was appointed a Member of the Order of the British Empire in the New Year Honours List of 1954.

At a ceremony in the Conference Room in Victory House on August 31, Mr. W. H. Bigg made a presentation to Mr. Bowering on behalf of his colleagues.

Mr. B. A. Copping, Experimental Officer, retired on August 31, 1956. He joined the Office in September 1920 as a Technical Assistant and during his service has served both at Headquarters and outstations. From 1946 until his retirement he has served at Thorney Island except for periods of temporary duty elsewhere.

Academic successes.—Information has reached us that the following members of the staff have been successful in recent examinations; we offer them our congratulations.

B.Sc. (General): S. G. Cornford (Second Class Honours).

City and Guilds Intermediate Certificate in Telecommunications Engineering: R. G. Flavell.

General Certificate of Education (Advanced Level): P. F. Abbott, J. M. Bayliss, Miss C. Bulpin, V. H. Farr, D. Gibbons, M. D. Gladstone, J. C. Howe, B. F. James, P. N. Mann, P. D. J. Rae, Miss M. Redding, Miss M. V. Roberts, L. P. Steele, E. H. Tucker, G. W. Tugwell, D. G. Ward and V. A. Winslow.

They all passed in one or more subjects.

Visit to Bracknell.—On the application of the Director, official permission was given for two visits by coach of representative members of the Headquarters staff and their wives to Bracknell, where the new Headquarters of the Office is to be built, to see the town and the types of houses and plots of land available. In a very wet summer both parties (one of non-industrial staff from Victory House, Harrow, Dunstable and Stanmore on August 20, and one of industrial staff from Harrow on August 23) were fortunate to have a fine afternoon for the trip. The Housing Manageress of the Bracknell Development Corporation personally conducted each party round the town and after tea, kindly provided by the Corporation, answered various housing questions.

WEATHER OF AUGUST 1956

As in July 1956 the Iceland "low" was missing from the pattern of mean pressures during August. The North Atlantic depressions travelled east on tracks passing across the British Isles and through the Baltic towards northern Russia. Pressure was high (1013–1015 mb.) over Greenland and Iceland (greatest anomaly +5 mb. near Reykjavik) and above normal in longitudes 20°–40°W. over the Atlantic. Pressures were below normal all over Europe, anomalies exceeding −5 mb. over a wide area of the Baltic, southern Sweden and Finland and locally in Britain and northern Italy. Over North America pressures were near normal, though depressions passed farther south than usual for August across Canada and there were pressure anomalies of +2 mb. to +4 mb. in the Canadian Archipelago.

There were no noteworthy anomalies of temperature over North America (generally ±0° to 1°C.), but temperatures appear to have been below normal over the Atlantic north of 50°N. and over all Europe north of a line from Gibraltar to the Alps (greatest anomaly −3°C. over the north European plain). Most of the Mediterranean, south-east Europe and Turkey were near normal or very slightly above. Temperatures were 1° to 2°C. below normal at nearly all Arctic stations.

There was above normal rainfall over most of Europe from the Alps northward, some places reporting the wettest August for up to 200 yr. (e.g. Geneva). Over twice the normal rainfall occurred in places as far apart as Bordeaux, Brest, Salzburg, Poland and Helsinki; whilst in Spain the totals ranged from 330 per cent. of normal on the north coast to much higher percentages in the usually dry southern districts (especially in the south-west). There was another

belt of excess rainfall, though with smaller anomalies, stretching right across North America in 45°–50°N. south of the Canadian depressions. Rainfall was generally somewhat below normal over southern United States, also in Norway and in south-east Europe. Less than a third of the normal rainfall fell in parts of Iceland and Greenland and locally in south-east Spain.

In the British Isles fronts and depressions moved across the country in succession throughout the month and there was a marked absence of anticyclonic activity.

On the 1st moderate to heavy rain spread from the south-west across most of the country and wind reached gale force in the English Channel as a deepening depression crossed northern England. In the polar air behind the depression, which persisted for about four days, showers and scattered thunderstorms occurred in most districts and were particularly heavy and frequent on the 5th and 6th. The 6th was the coldest August Bank Holiday at Kew for 30 yr., and during an unusually heavy hailstorm at Tunbridge Wells on that day, hailstones accumulated to a depth of 4 ft. in parts of the town during the course of an hour. The next few days were dry and sunny as the Azores anticyclone spread its influence north-eastwards; temperatures exceeded 70°F. in many places in southern England reaching 77°F. at Southend and 75°F. at Herne Bay. The warmer weather was short-lived, however, for a depression off Greenland deepened considerably as it moved towards Iceland and brought a return of dull cool weather to the British Isles on the 10th with widespread rain and occasional thunder. A succession of depressions from the Atlantic maintained generally unsettled weather until the 18th. A particularly vigorous one, which moved north-east across Northern Ireland and Scotland on the 13th, was accompanied by winds at gale force in the north and heavy rain in many places; nearly 2 in. of rain fell at Tiree during the night of the 12th–13th. A weak ridge of high pressure on the 14th brought a temporary return of sunny weather except in eastern Scotland, but temperatures, already below normal, became cooler still on the 16th as a trough, accompanied by widespread rain, moved eastward across northern districts. There was heavy rain again on the 18th (1·67 in. fell at Valley, Anglesey, from 0900 to 2100 G.M.T.) and gales occurred in the English Channel, associated with the progress of a further disturbance across the country. During the next two or three days pressure was lowest in the region of Scandinavia and winds over the country became generally north-westerly with frequent showers, occasional thunderstorms and some sunny periods, but on the 21st and 22nd a depression from the central Atlantic brought dull weather with periods of rain to southern England. The depression subsequently moved into northern France. Further disturbances gave two days of rain to most of the country although there were long sunny periods on the south coast on the 23rd, but on the 25th an influx of deep cold air from the north brought frequent thunderstorms to nearly all districts and for several days temperatures fell well below the normal. A secondary to the Scandinavian depression brought another two days of disastrous rain to north Wales and north-east England; there was a landslide down the Great Orme, Llandudno, and the worst floods for 40 yr. in the Colwyn Bay district according to local calculations, but perhaps the worst flooding occurred in the north of England and the Border Country where hundreds of acres of farmland were under water, road and rail communications were cut and houses and farms had to be evacuated. A northerly air stream developed over the country on the 31st and there were long sunny periods in the south.

The outstanding feature of the month was the high rainfall and this was accompanied by maximum temperatures which were 4°–6°F. below the average. Most places in the north of England had more than twice their normal amount of rain and in the north-west during the week 12th–18th there was more than four times the average amount. Bidston Observatory reported its highest total rainfall of any month since records began there in 1869. A "very rare" fall occurred at Arundel Castle, Sussex, on the 20th when 1·78 in. of rain fell in 18 min. Taking England and Wales as a whole it was the wettest August since 1917, and it has been the wettest summer (June, July and August taken together) for 25 yr.

In most areas the harvest was seriously delayed by the wet weather and was two or three weeks late. Incessant rain and heavy flooding caused a great deal of damage to corn land especially in the north, and hay lay rotting in the fields after it had been cut.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	77	31	−3·9	179	+6	89
Scotland	72	30	−3·8	151	+1	92
Northern Ireland ...	69	34	−3·5	167	+2	94

RAINFALL OF AUGUST 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	5·05	229	*Glam.*	Cardiff, Penylan ...	5·49	130
Kent	Dover	2·41	104	*Pemb.*	Tenby	4·02	106
„	Edenbridge, Falconhurst	2·86	109	*Radnor*	Tyrmynydd	7·64	142
Sussex	Compton, Compton Ho.	6·76	219	*Mont.*	Lake Vyrnwy	8·14	153
„	Worthing, Beach Ho. Pk.	2·56	113	*Mer.*	Blaenau Festiniog ...	17·90	160
Hants.	St. Catherine's L'thouse	4·73	246	„	Aberdovey	6·63	149
„	Southampton (East Pk.)	3·50	134	*Carn.*	Llandudno	8·07	286
„	South Farnborough ...	2·72	123	*Angl.*	Llanerchymedd ...	8·59	237
Herts.	Harpenden, Rothamsted	5·02	198	*I. Man*	Douglas, Borough Cem.	7·96	209
Bucks.	Slough, Upton	3·60	166	*Wigtown*	Newton Stewart ...	6·83	164
Oxford	Oxford, Radcliffe ...	4·52	198	*Dumf.*	Dumfries, Crichton R.I.	7·80	193
N'hants.	Wellingboro' Swanspool	4·47	188	„	Eskdalemuir Obsy. ...	8·88	172
Essex	Southend, W. W. ...	3·16	172	*Roxb.*	Crailing...	8·34	283
Suffolk	Felixstowe	3·88	222	*Peebles*	Stobo Castle	6·17	173
„	Lowestoft Sec. School ...	3·86	175	*Berwick*	Marchmont House ...	10·86	328
„	Bury St. Ed., Westley H.	4·63	178	*E. Loth.*	North Berwick Gas Wks.	6·17	198
Norfolk	Sandringham Ho. Gdns.	5·45	202	*Midl'n.*	Edinburgh, Blackf'd. H.	6·79	212
Wilts.	Aldbourne	4·02	145	*Lanark*	Hamilton W. W., T'nhill	5·16	151
Dorset	Creech Grange... ...	3·52	123	*Ayr*	Prestwick	6·27	197
„	Beaminster, East St. ...	5·93	190	„	Glen Afton, Ayr San. ...	8·26	153
Devon	Teignmouth, Den Gdns.	3·03	134	*Renfrew*	Greenock, Prospect Hill	5·40	105
„	Ilfracombe	5·07	141	*Bute*	Rothesay, Ardencraig ...	5·91	121
„	Princetown	7·36	108	*Argyll*	Morven, Drimnin ...	6·18	117
Cornwall	Bude, School House ...	...	...	„	Poltalloch	6·10	124
„	Penzance	3·18	100	„	Inveraray Castle ...	6·43	98
„	St. Austell	4·43	123	„	Islay, Eallabus	4·51	103
„	Scilly, Tresco Abbey ...	2·85	104	„	Tiree	7·59	181
Somerset	Taunton	2·04	86	*Kinross*	Loch Leven Sluice ...	6·34	166
Glos.	Cirencester	4·76	153	*Fife*	Leuchars Airfield ...	5·46	177
Salop	Church Stretton ...	5·17	155	*Perth*	Loch Dhu	8·51	126
„	Shrewsbury, Monkmore	4·74	171	„	Crieff, Strathearn Hyd.	6·73	160
Worcs.	Malvern, Free Library...	3·93	136	„	Pitlochry, Fincastle ...	5·88	166
Warwick	Birmingham, Edgbaston	4·98	167	*Angus*	Montrose, Sunnyside ...	4·80	172
Leics.	Thornton Reservoir ...	4·21	150	*Aberd.*	Braemar	6·64	195
Lincs.	Boston, Skirbeck ...	3·89	163	„	Dyce, Craibstone ...	3·31	109
„	Skegness, Marine Gdns.	3·14	129	„	New Deer School House	3·25	110
Notts.	Mansfield, Carr Bank ...	6·66	239	*Moray*	Gordon Castle... ...	3·64	115
Derby	Buxton, Terrace Slopes	10·67	244	*Nairn*	Nairn, Achareidh ...	4·40	181
Ches.	Bidston Observatory ...	8·71	283	*Inverness*	Loch Ness, Garthbeg ...	7·25	223
„	Manchester, Ringway...	7·93	241	„	Loch Hourn, Kinl'hourn	7·24	89
Lancs.	Stonyhurst College ...	11·57	229	„	Fort William, Teviot ...	4·05	65
„	Squires Gate	9·41	275	„	Skye, Broadford ...	6·11	95
Yorks.	Wakefield, Clarence Pk.	5·32	205	„	Skye, Duntulm ...	4·55	102
„	Hull, Pearson Park ...	5·21	179	*R. & C.*	Tain, Mayfield... ...	4·31	160
„	Felixkirk, Mt. St. John...	8·19	288	„	Inverbroom, Glackour...	7·90	189
„	York Museum	6·15	244	„	Achnashellach	6·76	107
„	Scarborough	4·80	173	*Suth.*	Lochinver, Bank Ho. ...	4·48	134
„	Middlesbrough... ...	6·62	242	*Caith.*	Wick Airfield	2·76	100
„	Baldersdale, Hury Res.	7·66	232	*Shetland*	Lerwick Observatory ...	2·37	79
Norl'd.	Newcastle, Leazes Pk....	7·30	259	*Ferm.*	Crom Castle	6·76	163
„	Bellingham, High Green	7·86	233	*Armagh*	Armagh Observatory ...	6·28	173
„	Lilburn Tower Gdns. ...	9·44	335	*Down*	Seaforde	7·90	211
Cumb.	Geltsdale	11·40	277	*Antrim*	Aldergrove Airfield ...	6·32	176
„	Keswick, High Hill ...	10·65	204	„	Ballymena, Harryville...	6·53	153
„	Ravenglass, The Grove	9·21	202	*L'derry*	Garvagh, Moneydig ...	6·54	167
Mon.	A'gavenny, Plâs Derwen	3·66	111	„	Londonderry, Creggan	5·91	128
Glam.	Ystalyfera, Wern House	8·38	136	*Tyrone*	Omagh, Edenfel ...	6·94	163

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